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Report No. 82

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**Engineering Report on the Type VI Microwave Refractometer**

Prepared Under Office of Naval Research Contract Nonr 375(08)
NR 371 034

ELECTRICAL ENGINEERING RESEARCH LABORATORY

THE UNIVERSITY OF TEXAS

REPORT NO. 82 15 APRIL 1956

# ENGINEERING REPORT ON THE TYPE VI MICROWAVE REFRACTOMETER


by

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C. E. Williams





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## FIGURES

## I. GENERAL DESCRIPTION

The Type VI Microwave Refractometer is an airplane carried instrument intended primarily for measuring large scale changes in the index of refraction of the atmosphere. In particular it is so constructed to be used for obtaining index of refraction profiles from ground level to altitudes of tens of thousands of feet. With the refractometer one can record changes in the index of refraction over a nominal 400 N unit [$N = (n - 1)10^6$, where n is the index of refraction] range on scales of 50 or 100 N units full scale.

The Type VI Refractometer consists of three principal components as shown on Figure 1: (1) the refractometer proper, (2) the power supply, and (3) the recording meter. Its basic principle of operation is exactly the same as that employed by the Type I Airborne Microwave Refractometer[1], and it is constructed along the same physical lines; however, it differs greatly in component design and construction.

The instrument makes use of two stabilized, near 9400 megacycles, oscillators and the beat frequency principle as shown in block form in Figure 2. The frequency of each of the stabilized oscillators is determined by the resonant frequency of an associated cavity resonator. One oscillator, called the reference oscillator, is controlled by a sealed cavity resonator or "reference cavity." The other oscillator, called the measuring oscillator, is controlled by an open cavity resonator or "measuring cavity." Changes of index of refraction of the atmosphere in the measuring cavity cause the resonant frequency of the measuring cavity and hence the difference frequency between the two stabilized oscillators to change. The change in resonant frequency of the measuring cavity is directly proportional to the change in index of refraction of the gas in the measuring cavity.

It may be shown [1] that for a resonator operating near 9400 megacycles the change in resonant frequency caused by a change in index of refraction of the contained gas of 1 N unit will be 9400 cycles; hence an amplifier-discriminator (See Figure 2) having a linear output voltage versus frequency over 400 x 9400 cycles or about 3.7 megacycles is necessary for an instrument having a 400 N unit useful range.

The outputs of the two stabilized oscillators are mixed in a hybrid junction and the difference frequency extracted. This difference frequency is amplified and limited by a conventional amplifier and applied to a discriminator having a linear slope characteristic over approximately a four-megacycle range. The output of the discriminator is applied to a linear differential amplifier which in turn drives the pen of a recording meter. Thus, the change in pen position of the recording meter is directly proportional to the change in the index of refraction of the medium in the sampling resonator.

The resonant frequency of a cavity resonator is determined not only by the index of refraction of the gas it contains but also by its dimensions. For the change in pen position of the recording meter to be due entirely to a change in index of refraction of the gas in the measuring cavity, the dimensions of both

[1] C. M. Crain, "Final Engineering Report on the Type I Airborne Microwave Refractometer," EERL Report No. 5-01, The University of Texas, 15 December 1952.

cavity resonators must be independent of temperature and pressure. While it is not possible to construct cavities having such characteristics, they may be constructed such that the dimension effects are small and normally negligible. A cavity resonator constructed of ordinary treated invar will have a temperature-frequency characteristic such that one degree Centigrade change in temperature of the invar will cause the resonant frequency of the resonator to change about the same amount as a change of one N unit in the index of refraction of the contained gas.

If both the reference resonator and the measuring resonator are subjected to the same environment, the changes in resonant frequency of the resonators should be approximately compensating; however, as the measuring cavity is normally mounted exterior to the aircraft and has a circulation of air on both its inner and outer sides, whereas the reference resonator is normally inside the aircraft and is sealed, the difference in temperature between the two cavities may become appreciable. Experience has shown also that such apparently obvious techniques as machining the resonators out of a common block of metal are entirely unsatisfactory due to temperature differences set up in the common block due to different circulation rates and other effects. The cavities for the Type VI Refractometer have been built to be temperature compensated. The bodies of the cavity and one end plate are fabricated from treated invar and the second end plate of the cavity is made using a steel plug pressed on an invar plate. With this arrangement it is possible to produce with reasonable effort cavities having temperature coefficients of less than an equivalent of 0.3 N unit per degree Centigrade. Each cavity using this construction has a somewhat different temperature coefficient and a calibration for the cavity is supplied with each cavity.

Since the reference resonator is sealed, the pressure difference between the inner and outer surfaces varies with atmospheric pressure and hence altitude. For a typical reference resonator this change in pressure causes the resonator frequency to change an equivalent of near .003 N unit per millibar change in pressure. This change is linear with pressure change over the range of pressures involved in refractometer applications.

As an example of the magnitude of the errors due to cavity resonator dimension effects the following figures are somewhat typical for an assumed index of refraction profile measurement from ground level up to 10,000 feet at a normal climb rate of about 500 feet per minute.

1. Assume a temperature change of 15° C and a pressure change of 300 millibars over the 10,000 height interval. Also assume the reference cavity is subjected to outside pressure change; i.e., the airplane is not pressurized.

2. Assume the measuring cavity and reference cavity have temperature coefficients of an equivalent +0.2 N per degree Centigrade and +0.2 N per degree Centigrade. (A + coefficient means the cavity gets larger when heated.)

3. Assume the reference cavity has a pressure coefficient of an equivalent .003 N unit per millibar.

4. Assume the measuring cavity becomes 15° colder and the reference cavity becomes 5° C colder.

5. The reference cavity will cause an error of 300 x .003 - 0.2 x 5 = .9 - 1.0 = .1N.

6. The measuring cavity will cause an error of opposite sign of 0.2 x 15 = 3.0 N.

7. The actual total accumulated error, for the numbers chosen, will then be 3.0 - .1 = 2.9 N unit over the 10,000 feet interval.

8. A typical index of refraction change over the 10,000 foot interval would be near 120 N. Hence, for the figures chosen, the error would be normally negligible.

9. Had the figures +0.2 N per degree C and +.2 N per degree C been, say +.2 N per C and $-0.3^{o}$ N per degree C the measured curve would be in error 300 x .003 + .3 x 5 + .2 x 15 = 5.4 N out of approximately 120 N. This last case would represent the worst condition attainable, i.e., all the errors are additive. However, knowing the calibration values for the cavities and knowing the temperature change only approximately one should be able to correct the measured curve to within at least no more than 1 N unit total error.

Another error can arise from dynamic effects involved in sampling the air. This error depends on the method of mounting the measuring cavity in the airstream. Wind tunnel tests have shown that for air speeds in the range of 100-200 miles per hour this error can be made as low as .1 N unit per 10 miles per hour change in aircraft speed.

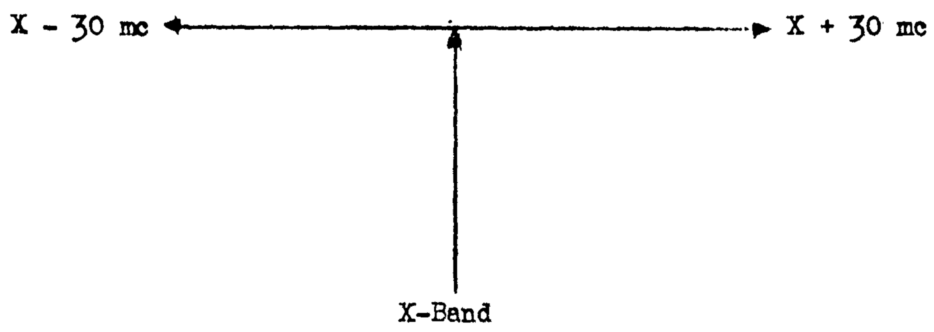
## II. DESCRIPTION OF STABILIZED OSCILLATORS

### A. General Operation

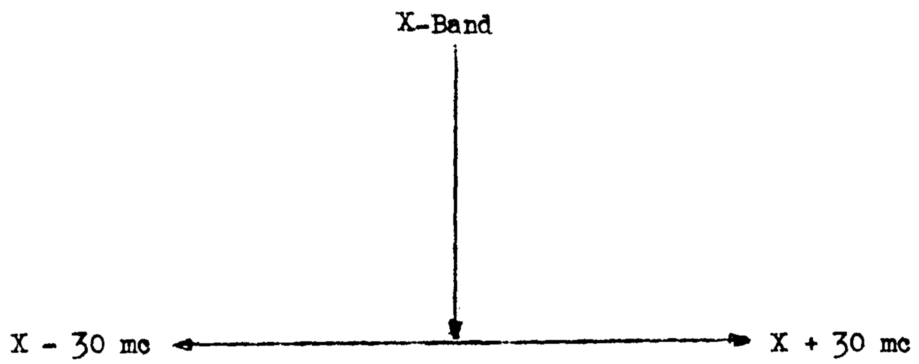
The reference and sampling stabilized oscillators are identical electrically; hence the following description applies to either unit.

The stabilized oscillators are in fundamental principle the same as described by Pound in December, 1947, issue of the Proceedings of the Institute of Radio Engineers, with the exception that the arms of the hybrid junction containing the receiver and modulator crystals have been interchanged as suggested by Tuller in the June 1948 issue of the Proceedings of the I.R.E.

Figure 4 shows a block diagram of a stabilized oscillator unit. The output of the klystron oscillator divides at Junction A, half going to Junction B and half to Junction C, where it mixes with the output from the second stabilized oscillator to provide a difference frequency for the metering amplifier as indicated in Figure 2. Power entering Junction B divides approximately equally between the modulator crystal and cavity resonator arms. The modulator crystal ideally is matched when it has zero 30 mc voltage across it; hence when driven by a 30 mc voltage from the 6C4 oscillator, it reflects sidebands of carrier ±30 mc but no X-band carrier. Ideally it is nothing more than a suppressed carrier generator. The energy entering the cavity resonator arm is reflected from the cavity resonator according to the reflection coefficient of the cavity resonator and enters the receiver crystal arm and arm containing the attenuator. The latter energy is of no consequence, as it is prevented from traveling to Junction B by hybrid Junction A. The phase and amplitude of the signal which is reflected from the cavity resonator and which enters the receiver crystal arm are dependent on the cavity reflection coefficient. The phase may also be varied by means of the phase shifter in the cavity resonator arm. The following vector diagram shows, for an oscillator frequency slightly above the cavity resonator's resonant frequency, the ideal relations among the X-band signals arriving at the receiving crystal when the phase shifter has the optimum setting and when the cavity is matched to the wave guide at resonance.

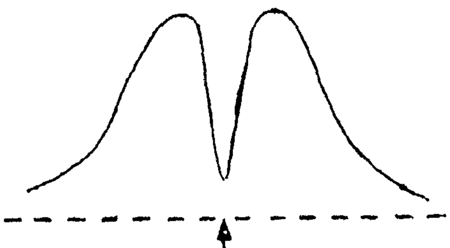



Similarly, the sketch below shows the vector diagram for an oscillator frequency slightly below the resonator's frequency.




In both the above cases the phase shifter has been adjusted such that the carrier and sidebands are in quadrature at the receiver crystal. If the phase shifters were adjusted to give $45^\circ$ additional phase shift (i.e., $90^\circ$ for two-way transmission) the signal at the modulator crystal would be of the phase modulated type instead of the desired amplitude modulated type.

If the oscillator and resonator frequencies are identical, the carrier magnitude is, assuming an ideal hybrid junction, zero at the receiver crystal except for a component due to the real component of the cavity reflection coefficient and a component due to not having the modulator crystal properly terminated when zero i-f voltage is across it. If the phase shifter has the correct setting, the component due to cavity mismatch of resonance causes primarily a double frequency (60 mc) signal at the receiver crystal and can be neglected for all practical purposes. The component due to modulator crystal mismatch causes a 30 megacycle output at the receiver crystal; hence it should, for best performance, be made as small as possible. If the phase shifter is set to give the vector relations shown above and the oscillator frequency is swept through a range of several megacycles, the magnitude of the 30 mc voltage appearing at the input and output of the 30 mc amplifier ideally should be as sketched below.



Resonant Frequency of Resonator

The above curve is obtained by turning the sweep switch to ON and connecting an oscilloscope between the test point on the 30 mc amplifier and ground. The AFC-MAN switch for the circuit under test should be on MAN and the I-F gain should be reduced to avoid limiting. As the oscillator frequency goes through the resonant frequency of the cavity resonator, the phase of the 30 mc signal in the i-f amplifier changes $180^{\circ}$ since the cavity resonator changes from capacitive to inductive or vice versa. (The fact that the 30 mc voltage changes phase $180^{\circ}$ is indicated by the vector diagrams on page 4.)

The output of the 30 mc amplifier feeds the control grid of the 30 mc mixer tube (6BE6), and the third grid is driven by another 30 mc voltage from the 30 mc oscillator as shown in Figure 4.

The change in plate current of the mixer tube is then given by the expression

$$i_p = g_m \, e_{g1}$$

where for purposes of analysis we can write

$$g_m \cong K E_{g3} (1 + \sin wt) \quad \text{and}$$

$$e_{g1} = E_{g1} \sin (wt + y)$$

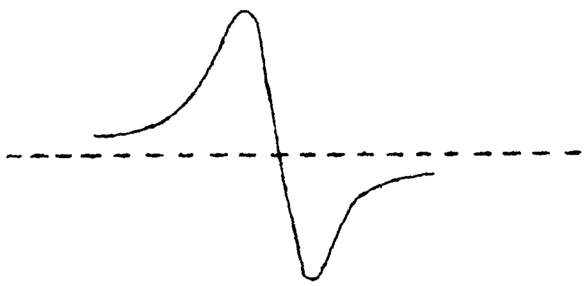
or

$$i_p = E_{g1}\, KE_{g3}\, [(1 + \sin wt)\, \sin (wt + y)]$$

$$= KE_{g3}\, E_{g1}\left[\sin(wt + y) + \left(\frac{1 - \cos 2\,wt}{2}\right)\cos y + \cos wt \sin wt \sin y\right]$$

$$= \tfrac{1}{2}KE_{g3}\, E_{g1}\, (\cos y) + 30 \text{ mc and higher harmonics}$$

If the d-c component of $i_p$ is to be a maximum, y must be zero or 180°; hence for maximum change in the d-c plate voltage of the mixer for a given change in i-f amplifier voltage the 30 mc voltage fed directly from the 30 mc oscillator should be in phase (or 180° out of phase) with the amplifier output. The instrument has been built such that the optimum phase relation exists. When the output vs. frequency curve for the 30 mc amplifier has the shape shown on page 5, the 6BE6 mixer plate voltage vs. frequency wil have the following shape:



Mixer Plate Voltage

The above curve is obtained by turning the SWEEP switch to ON and connecting the oscilloscope between the test pin labeled MIXER PLATE and ground.

The double-humped 30 mc amplifier curve is converted into a discriminator curve at the mixer plate due to the 180° phase difference in the two humps.

The quiescent mixer plate voltage should be adjusted to be approximately the same as the manual repeller voltage necessary to tune the klystron for maximum output at the resonator frequency. If the oscillator is to "lock in" when the repeller is switched from manual to AFC, the mixer plate voltage must become less negative when the manual repeller voltage is made more negative and vice versa. If the change is in the wrong direction, it is necessary to change the phase shift

180° by adjusting the phase shifter in the wave guide arm supplying the cavity resonator. (As explained later, the instrument has been wired such that when the phase shifter has the proper setting and the refractometer panel meter is in the MIXER PLATE position the meter will swing sharply from up-scale to down-scale as the manual repeller knob is slowly advanced in the clockwise position.)

## B. Analysis of Components of Stabilized Oscillators

### 1. 30 mc Amplifier and 30 mc Mixer

The two I-F Amplifier and Mixer sub-chasses shown in Figure 3 contain the following components: (1) a staggered-triple amplifier, (2) a cathode follower, and (3) a mixer. A schematic diagram of the amplifier-mixer unit is shown in Figure 5. The two 6AK5 stages and the pentode unit of the 6U8 form a staggered triple amplifier. The first 6AK5 stage is tuned to near 28.6 mc, the second 6AK5 stage is tuned to near 31.4 mc and the pentode section of the 6U8 is tuned to 30 mc. The input circuit to the first 6AK5 and the cathode follower are tuned to near 30 mc. The over-all response of the amplifier is adjusted to be essentially flat over a 2 mc range with the center of the pass band at 30 mc. The over-all maximum gain of the amplifier is approximately 10,000. The gain may be reduced by biasing the grid of the first 6AK5. This control is marked "IF-GAIN" and is placed on the front panel of the main refractometer chassis.

The cathode follower between the staggered triple amplifier and the 6BE6 mixer is for the purpose of providing a low impedance between the grid of the 6BE6 mixer and ground. This is necessary because the 30 mc voltage (near 10 volts) impressed on the third grid of the 6BE6 is coupled to the first grid by the inter-electrode capacitance between the first and third grid; hence for low residual 30 mc voltage on the first grid a low grid impedance is necessary. With the arrangement used in Figure 5, this residual signal is near 0.1 volts.

The output of the amplifier may be monitored at the test position marked "TP" on the top of the amplifier sub-chassis. The voltage output of the amplifier is coupled by a 5 micro-micro farad condenser to a 1N34 shunt rectifier, and the output of the rectifier is filtered and applied to the test jack. To measure the output of the amplifier a high impedance voltmeter should be connected between the test position and ground. Due to limiting action in the 6BE6 grid circuit the maximum voltage available at the test position is near 4 volts d-c.

The mixer stage employs a type 6BE6 tube. The plate is connected through a 100K resistor to the +100 supply. With these circuit constants the 6BE6 plate potential, and hence the potential on the AFC side of the repeller switch (see Figure 4) may be varied through a range of approximately 0 to -200 volts by means of the variable 15K resistor connected between the screen of the 6BE6 and ground. Both the fixed 20K and variable 15K screen resistors are mounted external to the 30 mc amplifier mixer sub-chassis as indicated in Figure 5. The 15K potentiometer is mounted on the refractometer front chassis and is labelled "MIXER." The plates of each of the mixers (one each for the reference and sampling stabilized oscillators) are connected to terminals on the front-panel meter selector switch and are also connected to test positions on the front panel in order that the plate voltages on the mixer tubes may be monitored as desired and also to assist in placing the refractometer in operation as described in Section IV. These meter selector switch positions are labelled "FREQ CONTROL."

A voltage of near 10 volts is impressed on the third grid of the 6BE6 mixer. This voltage is developed in the oscillator sub-chassis (see Figure 6) and is coupled to the amplifier-mixer chassis by a short section of RG 58A/U cable as shown in Figure 3. The adjustment and measurement of this voltage is discussed in Section II-B (2) below.

2. 30 mc Oscillator Sub-Chassis Components

Figure 6 shows a schematic diagram of the 30 mc Oscillator Sub-Chassis. This sub-chassis is mounted on the top side of the main refractometer chassis as shown in Figure 3. The purpose of this chassis is to provide 30 mc voltages to drive the modulator crystals (see Figure 2) in each of the stabilized oscillators and also to provide the 30 mc voltages for the third grids of the 6BE6, 30 mc mixers.

The 30 mc oscillator makes use of a 6C4 triode, a James Knight overtone crystal and an ordinary tuned plate oscillator circuit. The output of the 30 mc oscillator at the plate of the 6C4 is capacitively divided and applied to the two modulator crystals and the third grids of the two 6BE6's. The sizes of the condensers in the divider circuits have been chosen and adjusted so that when the 30 mc voltage at the plate of the 6C4 is a specified value the various outputs will be of appropriate magnitude. Thus, the only adjustment necessary, or even possible, on the 30 mc oscillator sub-chassis is the inductance in the plate circuit of the 6C4. Varying this inductance changes the tuning of the oscillator plate circuit and hence causes the output of the oscillator to change. The tuning of the inductance should <u>not</u> be for maximum oscillator output but should be inductive enough to insure that the oscillator will be self-starting. As shown in Figure 6, provision has been made to measure the 30 mc output. The plate of the 6C4 is coupled through a condenser to a shunt rectifier, and the output of the shunt rectifier is applied to a test position. By inserting a high impedance voltmeter between this test position and ground one may then measure the oscillator output. The circuit design and tuning is such that with properly performing 30 mc crystal and a normal 6C4 tube the d-c output at the test point is greater than 30 volts. By increasing the plate circuit inductance one may increase this voltage up to 50-60 volts; however, for output voltages above about 40 volts the oscillator will become non-self-starting.

With the oscillator output adjusted to its proper value of 30-35 volts and the capacitance dividers as shown in Figure 6 approximately 10 volts rms., 30 mc voltage is applied to the 3rd grids of the 6BE6 mixer tubes. Also crystal currents in the range 0.5 to 2.0 milliampere exist in the 1 N 23B modulator crystals. These currents may be measured by inserting a milliammeter in the test jack. (There are separate jacks for both modulator crystals.) For this measurement one should make sure that the repeller of the associated klystron oscillator is so adjusted that the klystron is inoperative; otherwise, the milliammeter reading will be the result of both 30 mc drive and near 9400 mc drive.

Crystal current due to klystron X-Band energy may also be measured at the phone test jacks. In order to measure current due only to X-Band signal, the

30 mc oscillator should be made inoperative by disconnecting the Amphenol plug which provides power to the oscillator chassis.

3. Klystron Circuits

Figure 7 shows a schematic diagram of the circuits directly related to the klystron oscillator tubes. Two switches, one for each oscillator, labelled "AFC-MAN" are mounted on the front panel. With the switch in the MAN position the repeller of the klystron is connected to a manually variable negative d-c voltage. Variations in the negative repeller voltage for each klystron are made by means of its associated potentiometer. These potentiometers are mounted on the front panel of the refractometer and are labelled "MANUAL TUNING." The sizes of the potentiometers and associated resistors have been chosen such that the repeller voltage on the klystron may be adjusted for operation in the third mode, (near -100 volts). When the AFC-MANUAL switch is turned to AFC, the repeller of the associated klystron is connected directly to the plate of associated 30 MC mixer. This is the position for normal operation of the instrument in measuring index of refraction. The procedure used to put the instrument in operation is described in Section IV.

For alignment and testing of the equipment provision has been made to sweep the repeller voltage. Six a-c volts are coupled through a .25 micro-farad condenser to the switch labelled "SWEEP" mounted on the front panel. Since another .25 micro-farad condenser is connected between repeller and ground the actual a-c voltage at the repeller is only about 3 volts rms. With the SWEEP switch in the ON position this a-c voltage is applied to the repeller circuit as shown in Figure 7.

4. Waveguide and Associated Plumbing

The waveguide and associated X-Band elements have been fabricated from standard 1" x 1/2" rectangular tubing.

These X-Band components have all been tuned to the correct operating condition and the tuning screws locked and sealed with glyptol. The tuning of the various X-Band elements is not critical; hence it should never be necessary to make adjustments to any of waveguide components except perhaps the tuning screws on the crystal holders. If these tuning screws are changed, follow the detailed procedure given on the following page. In the event it becomes necessary to change one of the IN23B crystals, a slight improvement in the overall operation may be effected by adjusting the tuning of the associated crystal holder; however, the characteristics on IN23B crystals are nearly enough alike and the overall effect of a small crystal mismatch so slight that the re-tuning should not be essential for satisfactory stabilized oscillator performance. The changing of a crystal should not be done unless it is certain that the crystal is malfunctioning. (See pages 17-18 of this manual.

Junctions A, B, and C in Figure 4 are ordinary hybrid junctions or magic tees. These junctions have been fabricated such that their characteristics are optimum and no provision has been made for tuning or adjustment.

The attenuators in the waveguide arms have been set to give about 9 db. attenuation between Junctions B and A, about 3 db. attenuation between B and C and about 3 db. between the klystron and junction A. (See Figure 4) The attenuation between arms B and A should not be reduced appreciably as isolation between the klystron and cavity resonator prevents the resonator from "pulling" the oscillator.

The phase shifter in the cavity resonator arm of Junction A has been designed to give a phase shift from 0 to 180 degrees as the polystyrene strip is moved into the guide. The phase shifter is adjusted properly at the initial installation of the refractometer and it will not be necessary to change the phase shifter adjustment unless the length of the cavity resonator arm is changed. In case the arm length is changed, the phase shifter must be reset using the procedure given in Part V. No phase shifter is used in the reference resonator arm. The length of this arm is adjusted to give the proper phase shift when the arm is fabricated.

Optimum stabilized oscillator performance is obtained when the modulator crystal arm is properly tuned. The impedance of the crystal is a function of the power incident upon the crystal and the impedance into which the crystal works. In order to duplicate as closely as possible these factors the following procedure has been used for tuning the modulator crystal arm.

a. The complete wave guide assembly (or at least Junctions A and B as shown in Figure 4) is set up as normally used in the refractometer.

b. The attenuator between Junctions A and B is adjusted to its normal operational condition (approximately 9 db.).

c. The cavity resonator is replaced by a matched load. (VSWR 1.05)

d. The meter selector switch is tuned to the appropriate XTAL CURRENT position.

e. The Amphenol connector which couples power to the oscillator chassis is disconnected so that the modulator crystal has no 30 mc voltage.

f. The tuning screws in the modulator crystal holder are adjusted such that the receiver crystal current as read on the panel meter is a minimum. This current should be less than 1 microampere. (If the procedure given next for tuning the receiver crystal holder results in appreciable increase in receiver crystal current the above procedure should be repeated.)

g. As an additional procedure to part (f) one may place a matched load on the cavity resonator arm, insert a d-c voltmeter to measure the output of the 30 MC amplifier and energize the 30 MC oscillator. The tuning of the modulator crystal is then adjusted until the 30 MC amplifier output is a minimum.

The receiver crystal holder is tuned by leaving the set-up as above except that the modulator crystal is driven by a 30 mc voltage. This should result in a receiver crystal current in the order of 10 to 60 microamperes. The tuning screws on the receiver crystal holder are adjusted to give maximum receiver crystal current.

# III. METERING CIRCUIT

## A. General Operation

The purpose of the metering circuit shown in Figure 8 is to convert the change in difference frequency between the two stabilized oscillators into a suitable change in deflection of the pen of a recording meter. Figure 2 shows in block diagram form the arrangement used. Approximately 30 mv. of difference frequency voltage is received at the input of the metering amplifier. This voltage is amplified, limited, and applied to the input of a two-tube discriminator amplifier and discriminator detector. The output of the discriminator detector is developed across a divider network such that scales of 50 and 100 N units are obtained.

In order that one may record on a 50-N unit scale anywhere throughout the 400-N unit range of the refractometer, arrangement has been made to add a calibrated "bucking" voltage to the output of the discriminator. Thus if the index of refraction (and hence the difference frequency and discriminator output voltage) changes so as to cause the EA recording meter in the plate circuit of the d-c amplifier (see Figures 2 and 9) to go off scale in either direction, the operator may turn one position the switch labelled "METER BIAS" (mounted on the front panel of the refractometer) and move the EA pen 8/10 of full scale in the desired direction. The METER BIAS switch is provided with a zero position, five add, and five subtract positions. Thus if one is recording on the 50-N unit scale he may add or subtract as necessary up to .8 x 50 x 5 or 200 N units from the center position.

The combined discriminator and meter bias voltages are applied between grids of a differential amplifier as shown in Figure 9. The output of the differential amplifier may be applied to either an EA meter for recording the relatively slow changes in index of refraction or through a suitable coupling condenser to a Brush or similar type recorder for recording the fluctuations in index of refraction having frequencies greater than approximately one cycle per second.

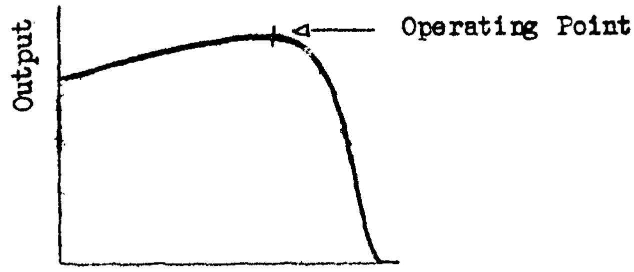
## B. Analysis of Components of Metering Circuit

### 1. Metering Amplifier and Discriminator

A schematic diagram of the components mounted on the metering amplifier chassis is shown in Figure 8. The metering amplifier receives the difference frequency signal between the two stabilized oscillators at Junction "C" as shown in Figure 4. The amplifier has a center frequency near 43 megacycles and a bandwidth of approximately 7.5 megacycles. This bandwidth is necessary if the refractometer is to have a linear range of approximately 400 N units, as the voltage applied to the discriminator circuit must be practically constant over almost a 4-megacycle range.

On the amplifier chassis are mounted four amplifier stages (the last two of which provide limiting action), a two-tube discriminator amplifier stage, and a discriminator detector stage.

The grid bias on the first stage may be varied by adjusting the control labelled "LIMITER" on the front panel. A IN34 crystal detector has been placed in the grid circuit of the discriminator amplifier and a connection made so that the input to the discriminator amplifier may be monitored. Thus, when the refractometer is in operation the operator may monitor the discriminator input and make certain that it remains at the value for which the refractometer was calibrated. This should be near the peak value as indicated on the meter on the front panel. The input to the discriminator amplifier should vary with amplifier grid bias similar to the sketch below.




The amplitude of the above curve is dependent on the screen voltage of the limiter. This screen voltage is supplied through a 0-5K variable resistor mounted on the front panel of the refractometer and labelled "CALIBRATE." The proper procedure for operation is, then, for the operator to peak the panel meter with the potentiometer marked "LIMITER" and adjust the meter reading to the calibration value with the variable resistor marked "CALIBRATE."

While the magnitude of the 43-MC input voltage to the metering amplifier is not critical, it must be large enough to allow the limiters to operate at the peak of the output curve above with the external grid bias at zero (i.e., the potentiometer labelled "LIMITER" set for a maximum output). The design is such that approximately 20 mv. input is adequate. By monitoring this meter switch position the operator can immediately detect any improper performance of the entire instrument except for the discriminator itself and the amplifier driving the recording meter. If the input to the discriminator varies slightly due to a large change in power output of the klystron tubes, for example, the operator may adjust the LIMITER and/or CALIBRATE control, as outlined above, until the input has the proper value. This value will be slightly different from unit to unit but is determined for each unit when it is calibrated by the procedure outlined in Section V.

When the discriminator input voltage is the proper value, the d-c voltage to ground from each cathode of the 6AL5 detector should be approximately 4 volts. The output of the 6AL5 detector is brought out through pens 9 and 10 of the Cannon plug connector through series variable resistances to a resistance divider network panel mounted on back of the RANGE SELECTOR switch.

2. Recording Meter Amplifier, Scale Selector and Range Adjustment Circuits

Figure 9 shows a schematic diagram of the recording meter amplifier and associated circuits. The refractometer is built to have a useful range of 400 N units and is built so that one may record on either a 50- or 100-N unit scale anywhere within this range.

The recording meter amplifier is a differential amplifier with the recording meter connected between the plates of the 12AT7. Index variations having a frequency greater than about 1 cycle per second may be recorded by connecting a Brush or similar type recorder with its associated amplifier in the circuit as indicated in Figure 9. Connectors for two separate recording meters are provided on the front of the Refractometer chassis.

The cathode of the 12AT7 is connected to -250 d-c through a 30K wire-wound fixed resistor and a 0-10 K variable resistor. The bias of the tube is adjusted to 1.2-1.5 volts by means of the 0-10 K resistor in the cathode circuit. This control is mounted on the top of the main refractometer chasis and is marked "12AT7 BIAS."

Approximately 0.6 volt difference in potential between the grids of the 12AT7 causes full scale deflection of the EA recording meter; hence the voltage developed across the ten 1000-ohm resistors in series must be approximately 3 volts (or 6 volts total grid-to-grid voltage change for both resistor strings from the points labelled -5 to +5 on the string in Figure 9). The voltage across the meter bias resistors in each grid circuit may be varied by means of series 10,000-ohm potentiometers. These potentiometers, one for each grid circuit as shown in Figure 9, are mounted on the front panel and labelled "RANGE." The voltage across the resistor strings may be monitored by turning the METER SELECTOR switch on the front panel of the refractometer to L-RANGE and R-RANGE respectively. These voltages should be approximately equal and should be adjusted so that, when one turns the "METER BIAS" switch on step, the EA meter changes 8/10 full scale.

The recording meter should be adjusted mechanically to read mid-scale when disconnected. With the 12AT7 circuit active the meter may be re-zeroed to mid-scale by turning the METER BIAS switch to "0" and the RANGE SELECTOR switch to "OFF" and then adjusting the potentiometer in the plate circuit of the 12AT7. This potentiometer is mounted on the front panel and labelled "ZERO ADJUST." The EA meter may drift slightly for approximately five minutes after energizing the equipment due to the warming up of the 12AT7.

## IV. PROCEDURE FOR OPERATION AND TROUBLE-SHOOTING SUGGESTIONS

The steps outlined in the following paragraphs represent merely a suggested guide for operation of the refractometer. It is believed that if the following steps are followed, however, the operator should experience little difficulty in operating the refractometer. This section will attempt to give not only the procedure for operation but also trouble shooting and maintenance suggestions in case of improper performance at any stage in the operation.

A. Procedure for Operation

Before a detailed discussion of the procedure for operation and trouble-shooting is considered one should first examine the following step-by-step procedure for operation. The following step-by-step procedure is the routine procedure to be followed in placing a properly performing refractometer in operation:

1. Turn AFC-MAN switches on refractometer to MAN.

2. Turn RANGE SELECTOR and METER BIAS controls to OFF and 0 respectively.

3. Turn the panel meter selector switch to the OFF position.

4. Mechanically adjust the pens of the recording meters to read mid-scale. For this adjustment the recording meter should be disconnected from the refractometer electrically.

5. Adjust voltages of 60-400 cycle power source to lie in the range 110-120 volts.

6. Turn filament switch on refractometer power supply to the ON position.

7. After 30 seconds turn plate switch to the ON position.

8. After a wait of at least two minutes turn the meter selector switch to the L-XTAL CURRENT position and turn slowly the left MANUAL TUNING control. The panel test reading vs control rotation should be as indicated in the figure on page 16. The dip occurs when the klystron frequency is the same as the resonant frequency of the cavity resonator. With the control adjusted such that the test meter reading is minimum throw the left AFC-MAN switch to MAN. The test meter reading must remain at the bottom of the dip if the klystron is locked to the cavity.

9. Turn the meter selector switch to the R-XTAL CURRENT position and repeat step 8 for the right-hand oscillator.

10. Turn the meter selector switch to the LIMITER position.

11. Check that the recording meter is adjusted to mid-scale and if necessary set to mid-scale using the ZERO ADJUST control.

12. Turn the RANGE SELECTOR switch to the 50N or 100N position and turn the METER BIAS switch to a position such that the pen of the recording meter is on scale.

13. Check that the setting of the LIMITER control is such that the panel test meter reading is the maximum obtainable when the LIMITER potentiometer is adjusted.

14. Check that the maximum meter reading obtained by peaking the LIMITER control is the specified calibration value. If this peak value is not the specified calibration value, adjust the CALIBRATE control such that the panel meter

reads the specified calibration value and recheck the LIMITER peaking as specified in step 13.

To turn the refractometer off one should turn the RANGE SELECTOR and METER BIAS switches to the OFF and 0 positions respectively, turn the plate and filament switches on the power supply to the OFF position and place the AFC-MAN switches in the MAN position.

B. <u>Discussion of Routine Operation Procedure and Trouble-Shooting Suggestions</u>

The material which follows will discuss in detail the above listed "Procedure for Operation" and will outline trouble-shooting procedures when faulty operation occurs anywhere during the operation. This material applies for operating and trouble shooting a unit which has been set up and placed in initial operation using the procedure detailed in Section V, p. 18 of this manual.

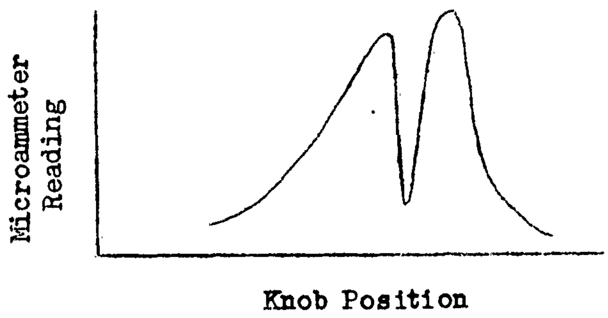
Before energizing the equipment the pen of the Esterline-Angus recording milliammeter should be mechanically adjusted to read mid-scale. This assures that the balanced linear differential amplifier will operate over its optimum range. The lever for this adjustment is located directly below the take-up spool.

The RANGE SELECTOR switch should be set on OFF, the METER BIAS switch should be set on "0" and the AFC-MAN switches should be set on MAN. The former assures that the recording meter will not receive abnormal current during warmup and the latter assures negative tending repeller voltages on the klystrons during warmup.

The equipment may be energized by turning on first the filament switch and then after about 30 seconds turning on the plate switch. The delay between energizing the filament and plate circuits insures that abnormal voltages will not be developed by the power supply during warmup. The pilot lights on the power supply should glow. Failure of the pilot lights to burn indicates (1) open fuse, (2) burned out pilot bulb, or (3) no 110-120v., 60-400 cycle, supply voltage. A periodic check of the d-c regulated voltages (-250, +100, and +250) should be made. In the event of improper performance of any kind in the use of the instrument these voltages should be checked first in the trouble-shooting routine.

The operator should wait at least two minutes after turning the plate switch on before attempting to continue with the "placing in operation" procedure. This delay is necessary to allow adequate warmup time of the klystron oscillators and other tubes in the refractometer. If one attempts to "lock in" the stabilized oscillators (step 8 and 9 of the procedure) before adequate warmup, he may find that the unit does not have the proper characteristics as the manual tuning repeller control is adjusted and hence may improperly suspect trouble.

After the two or three minute delay the two stabilized oscillators may be "locked in." The metering switch should be advanced to the L-XTAL CURRENT position. With the switch in this position the panel meter is connected to read the X-band power delivered to the receiver crystal (see Figure 4). If the klystron Mechanical Frequency Adjustment is proper the L-XTAL CURRENT as indicated on the panel test meter should vary with the manual tuning Knob position as indicated in the sketch below. This simply means that the klystron is putting out maximum power at the resonant frequency of the cavity resonator. With the manual tuning control set such that the panel meter reading is a minimum, the AFC-MAN switch should be turned to MAN, and the meter reading should remain at the minimum of the sharp dip in the curve. If the meter reading does not remain at the minimum of the dip, the klystron is not locked to the cavity resonator, and the stabilized oscillator is not performing properly.




All that normally is necessary once the proper manual tuning control setting has been made is to turn the AFC-MAN switch to the AFC position after the required warmup period delay. The panel meter reading should be some fixed value for lock-in for each klystron and when the AFC-MAN switch is placed in the AFC position the panel meter should read this value if lock-in conditions exist. This reading will be different, in general, for the different refractometers and will be different for the two oscillators in the same refractometer. As part of the operation of the equipment the operator should acquaint himself with the panel meter reading when the oscillator is operating correctly on AFC and should make sure the panel meter reads this value (the value will drift slightly for several minutes after energizing the unit due to temperature effects of the klystron characteristics) any time the unit is placed in operation as outlined above. If the meter panel meter does not read the normal locked in value when the switch is turned to AFC, one should return the switch to MAN, make slight adjustments in the setting of the MANUAL TUNING control to the position at minimum L-XTAL CURRENT as previously discussed, and then place the switch in the AFC position. Failure of the klystron to properly lock in, as best indicated by the panel meter reading, will be indicative of faulty operation somewhere in the associated AFC circuit. The following checks should reveal the difficulty:

1. Check that filaments of tubes are lit and that proper d-c voltages are delivered by power supply.

2. Failure of the panel test meter to deflect at all with the SELECTOR SWITCH in the L-XTAL CURRENT position will in all probability be due to one of two things--failure of the klystron tube or failure of the 1N23B crystal in the receiver crystal arm of the hybrid waveguide junction. Before removing the tube or crystal the voltages on the klystron should be checked with the voltmeter. The shell should be +250 with respect to ground, and the repeller potential should vary from about -80 to -120 as the manual repeller control is moved through its range. If the filament of the tube is open, the tube will be cold (CAUTION--the shell of the tube is 250 volts above ground). If the klystron voltages are correct, the 1N23B receiver crystal should be removed and checked with an ohmmeter using a high resistance scale. If the crystal is satisfactory, the klystron should be replaced. After replacing the klystron tube one must mechanically adjust the coarse frequency adjustment on the klystron tube as specified by the tube manufacturer until one obtains a microammeter reading vs. manual repeller control setting as shown on page 16. It is desirable to mechanically tune the klystron such that the spike in the curve occurs very near the center of the curve. This assures that when the oscillator is operating AFC the klystron is operating at an optimum point; i.e., near the center of a mode.

3. If the microammeter reading vs. manual repeller control setting curve appears as sketched on page 16, turn the panel test meter to the appropriate "FREQ CONTROL" position for the stabilized oscillator being investigated. With the switch in this position, the pannel test meter is connected between the mixer plate (6BE6, Figure 5) grid and ground and is approximately a 0 to -200 volt voltmeter. The manual tuning control should be <u>slowly</u> turned until the panel meter reacts sharply to a slight change in knob position. For proper operation the meter pen should swing off scale in both directions as the control is slowly turned and should swing rapidly from <u>down scale</u> to <u>up scale</u> when the manual repeller control is turned counterclockwise, or vice versa. If the panel meter reading (meter switch on appropriate "FREQ. CONTROL" setting) is still not as described above, one should check the 30 MC oscillator circuits. A 0-1-milliampere ammeter inserted in the jack on the oscillator chassis should read near mid-scale or higher when the klystron tube is not oscillating. (The jack on the left-hand side of the chassis when one faces the front panel of the refractometer is in the reference stabilized oscillator circuit and the jack on the right-hand side is in the measuring stabilized oscillator circuit). If the milliammeter indicates no modulator crystal current (see Figure 6), any of several things could be wrong. If the milliammeter shows no crystal current when the meter is inserted in either the left or right-hand jack, then in all probability the 30 MC oscillator is inoperative due to a faulty 6C4 tube, overtone crystal, or other circuit components. If the milliammeter shows crystal current in one modulator crystal but not the other, then in all probability the 1N23B modulator crystal is faulty.

If the receiver crystal and modulator crystal currents check satisfactory as outlined above and the basic system operation is still faulty, the trouble in all likelihood is in the 30 MC i-f amplifier strip. A routine trouble-shooting check should then be made of this unit. Except for tube failure, little trouble should be expected in this unit; hence a tube check should in most cases reveal the faulty element. A test pin jack is connected (see Figure 5) in the grid circuit of the 6BE6 mixer tube on the i-f strip. Operation of the entire i-f amplifier can be checked by applying a near 30 MC input voltage from a signal generator and measuring the output at the test jack with a high impedance 0-10-volt voltmeter.

After the reference oscillator has been placed in stabilized operation by the previously given procedure, the measuring oscillator may be placed in operation by exactly the same procedure. The operator should advance the meter switch clockwise to the R-XTAL CURRENT position, adjust the repeller control potentiometer so that the unstabilized klystron oscillates very close to the resonant frequency of the cavity resonator as outlined previously, and raise the right-hand AFC-MAN switch to the AFC position.

The procedure for trouble-shooting in event of improper performance is exactly as outlined previously for the left-hand or reference oscillator.

The operator should next set the EA meter to mid-scale by means of the control marked "ZERO ADJUST."

After the two oscillators have been placed in operation and the recording meter centered, the RANGE SELECTOR switch should be set to the scale on which it is desired to measure. The meter selector switch should then be advanced to the position labelled "LIMITER." With the switch in this position the panel meter reads approximately (see Figure 8, Cannon Plug Connection 6) proportional to the near 43 MC voltage developed at the input of the discriminator in the metering amplifier (front sub-chassis on top side of main chassis). The potentiometer marked "CALIBRATE" should be adjusted to the value for which the unit was calibrated. This value will be different for each refractometer, in general, and should be in the log book of the refractometer, and marked for ready reference on the front panel of the refractometer.

The meter selector switch should be left in the LIMITER position during the measuring period. The operator can detect any failure anywhere in the entire unit except the discriminator and metering d-c amplifiers circuits by monitoring the panel meter. The panel meter should stay at a value very close to the calibration value at all times. In the event of slight changes the operator should adjust the LIMITER or CALIBRATE control unit as outlined above so that the meter reads the correct value.

When the measurements have been completed the operator should turn the power supply switch off, turn the two AFC-MAN switches to MAN, and turn the three rotary switches on the Refractometer panel to the ZERO or OFF positions.

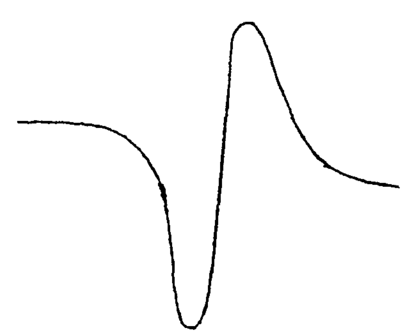
## V. ALIGNMENT AND CALIBRATION

This section deals mainly with the procedure to be followed after installing the refractometer in the airplane. It is assumed that the various components of the equipment are functioning correctly and that basic units such as hybrid junctions, crystals, i-f amplifiers, buffers, etc., have been individually and properly aligned. The procedure for alignment of the waveguide components is given in Section III. There should be no necessity for adjustment of the i-f amplifiers unless in operation a failure occurs, requiring modification inside the i-f amplifier chassis (for example, a plate coil replacement).

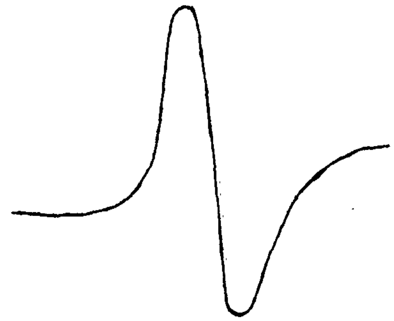
A. Adjustment of X-Band Phase Shifter

After the main refractometer chassis has been mounted in the airplane and the waveguide connection between the sampling cavity resonator and the waveguide components on the refractometer chassis installed, it will be necessary to adjust the polystyrene phase shifter in the measuring cavity resonator arm so that the proper phase between the X-Band carrier and side-bands is obtained as discussed in Section II. For this procedure one should place an oscilloscope between ground and the plate of the reference mixer tube (6BE6 in Figure 5). Test pins are provided on the front panel of the refractometer for this purpose. Also on the front panel, there is a switch labelled "SWEEP" which, except for the following procedure, should be in the OFF position. When the switch is in the ON position, 6.3 volts a-c are coupled through a 0.25 micro-farad condenser (Figure 7) to the repeller of the klystron. (Due to the .25 micro-farad condenser between the repeller and ground only about 3 volts rms is actually applied to the repeller.)

For making the phase shifter adjustment, the refractometer should be placed in operation as outlined in Section IV, except that the SWEEP switch should be turned to ON and the AFC-MANUAL switch should be in the MANUAL position. When the MANUAL REPELLER control potentiometer is turned through its range, a position will be reached such that the d-c repeller potential is the proper value to cause the klystron to oscillate at the resonant frequency of the cavity resonator (assuming the mechanical frequency adjustment of the klystron has been properly set as outlined in Section IV). At this value of d-c repeller voltage, due to the superimposed a-c voltage on the repeller, the waveform appearing on the oscilloscope should be approximately as follows:



To obtain the above wave form it may be necessary to decrease the gain of the i-f amplifier (potentiometer marked "GAIN" on left-hand side of unit for reference system and on right-hand side for measuring system) from its normal maximum position. By changing the penetration of the polystyrene into the waveguide the pattern can be changed to the desired shape. It may be that, for the oscilloscope used, the corect pattern will be, not as above, but the reverse as follows:



As the pattern obtained depends not only on the phase shifter but also on the polarity of the oscilloscope, all that can be stated here is that one is right and the other wrong; however, it may be readily determined by following the procedure of Section IV, i.e., noting that the panel meter (with the METER SELECTOR switch turned to the proper FREQ. CONTROL position) should have its sharpest deflection from down scale to up scale as the MANUAL REPELLER CONTROL is turned counter-clockwise. (SWEEP in OFF position for this check.)

When the proper waveform has been obtained and verified, the gain should be increased to its maximum value. Spurious deflections may be noted on the oscilloscope trace. These spurious deflections are of no important consequence, but it is important that the main response maintain approximately a symmetrical discriminator shape. It should be realized that when the gain is increased to its maximum value several additional factors are involved--the mixer will be going from saturation limiting to cut-off, for example.

The phase shift in the reference cavity arm has been permanently adjusted in the construction of the unit and will require no additional alignment.

B. Calibration of the Metering Circuits

The refractometer may be calibrated by connecting the output of a standard signal generator to the input of metering amplifier chassis (See Figure 4). The cable connecting the metering amplifier to the crystal in Junction C should be removed from the crystal holder and connected to the signal generator output terminal or cable. The resulting mismatch is of no consequence as is made clear later. All that is required is that the output of the signal generator be enough so that the limiter driving the metering discriminator amplifier (see Figure 8) can be peaked. This may be checked by turning the meter selector switch to LIMITER and increasing the near 43 MC output of the standard signal generator until the panel meter is peaked. (The frequency of the signal generator output should be such that the recording meter pen remains on scale.) During this procedure the control marked "LIMITER" should be set at approximately the same value as was necessary to operate at the peak of the limiter curve as outlined on page 18 in Section IV. The magnitude of the peak value itself is determined by the setting of the CALIBRATE control and should be held constant at the desired value (normally the value used for the last previous calibration).

Next, the frequency of the signal generator should be changed in steps and the resulting meter deflection noted. The slope of the resulting curve should be .106 N unit per kilocycle (or 1.0 N units per 9.44 kilocycles). If the slope is less, the CALIBRATE control should be advanced, and if greater, the control should be backed off. The resulting curve should be quite linear over the 400 N range. In the event the curve is not linear it will be necessary to make slight adjustments in the BALANCE control or perhaps even the discriminator alignment itself (see Figures 8 and 9).

The sensitivity of the 12AT7 recording meter amplifier (Figure 9) is a function to some degree of the grid bias. The bias may be changed by means of the 0-10K variable resistor in the cathode circuit of the 12AT7. The bias should always be adjusted to be in the range of -1 to -2 volts and will normally be near -1.3 to -1.5 volts when the refractometer is initially installed. To measure this bias one should turn the METER BIAS switch to 0, the SCALE SELECTOR switch to OFF, and measure with a d-c VTVM the potential of the 12AT7 cathode test point. The g/m of the 12AT7 is slightly effected by the frequency of the supply voltage; hence the calibration should be made using the same power supply frequency as is used in the airplane.

The ganged variable resistors labelled "BALANCE" in the cathode circuit of the discriminator diode are wired so that the resistance of one decreases as the resistance of the other increases. The primary function of these resistors is to balance the output of the discriminator diodes; however, a change in these resistors also changes somewhat the sensitivity and center frequency of the discriminator curve.

The most satisfactory way to approximately align the refractometer is to make use of a sweep generator (the refractometer may be used as a sweep generator by "locking in" one oscillator and sweeping the other) and oscilloscope. The output of the sweep generator should be applied to the input of the metering amplifier and the oscilloscope input connected between one EA terminal and ground. Final alignment is best made by using a signal generator and the point by point calibration procedure given above. Unless element replacements have been made in the discriminator itself, the sweep procedure is not needed. All that should be done is to make periodic checks of the calibration using the standard signal generator (perhaps every 100 hours of operation).

### C. Frequency Adjustment of the Sampling Cavity Resonator

The reference and sampling cavity resonators have been built to have a difference frequency very close to 40 mc, with the sampling cavity having the highest frequency. In order to operate over the most linear portion of the metering amplifier curve, the difference frequency has been modified by means of a screw protruding into one end plate of the measuring cavity so that near the ground in an atmosphere having an index of refraction of approximately 300 N units, and with operation on the 50 N scale, the EA meter is on scale when the METER BIAS SWITCH is set at -2 or -3. If for any reason it is desired to change the difference frequency, it will be necessary to loosen the set screw which clamps the frequency adjustment screw. The frequency adjustment screw may then be reset to the desired position.

## VI. REFRACTOMETER POWER SUPPLY

A schematic diagram of the power supply for the microwave refractometer is shown in Figure 10. This power supply may be used with a source of 60-400 cycles. The power supply makes use of conventional regulation circuits. The -250 supply provides a reference voltage for the +100 and +250 circuits; hence in adjusting the output voltages the procedure is to first set the -250 volt supply to that value by inserting a d-c voltmeter between the test point labelled -250 and the ground test point on the front panel of the power supply and then to adjust the potentiometer immediately below the -250 test point such that the output is -250 volts. The same procedure should then be followed for the +100 and +250 volt circuits. In the event the adjusting of the various voltage adjustment potentiometers fail to provide the specified output the power supply has some faulty element, and the following procedure is suggested in isolating the difficulty:

1. Measure the input supply voltage. Make sure that near 115 volts, 400 cycles or 60 cycles are supplied.

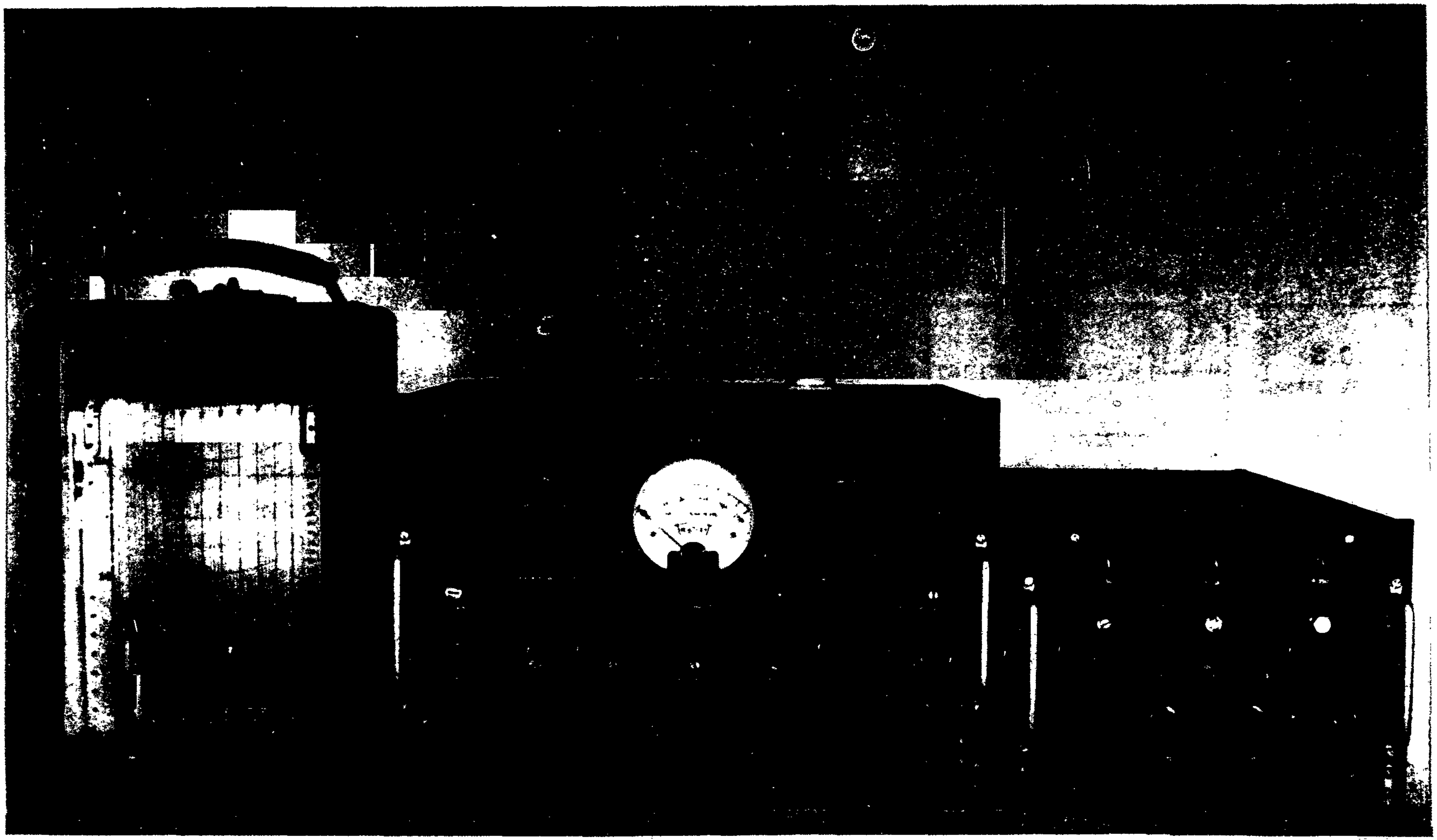
2. Check the load on the power supply for shorts or abnormal load currents.

3. If the -250 supply indicates proper regulation and the +100 and +250 are both faulty check the rectifier tubes in the plus supply.

4. Next, check the various tubes in the plus regulators.

5. In the event all tubes are normal it will be necessary to check the potentials on the various tube electrodes to isolate a faulty resistor or condenser. All control grids should be negative at a value typical for the tube in question.

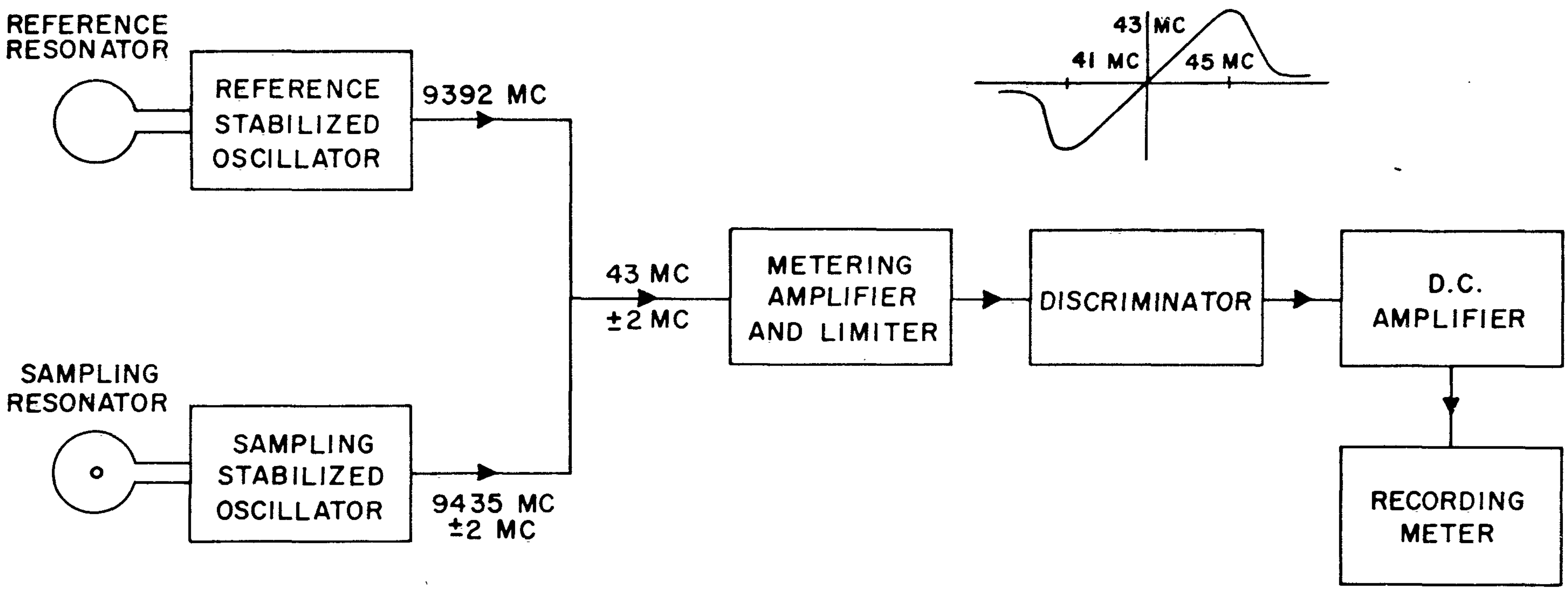
6. If the -250 supply is faulty in all likelihood it will cause the +100 and +250 supplies to likewise be faulty, as it provides their reference voltages. Hence, it should be given the same check outlined in Part 1 through 5 before attempting to isolate trouble in the plus supplies.



RECORDING METER | REFRACTOMETER | POWER SUPPLY

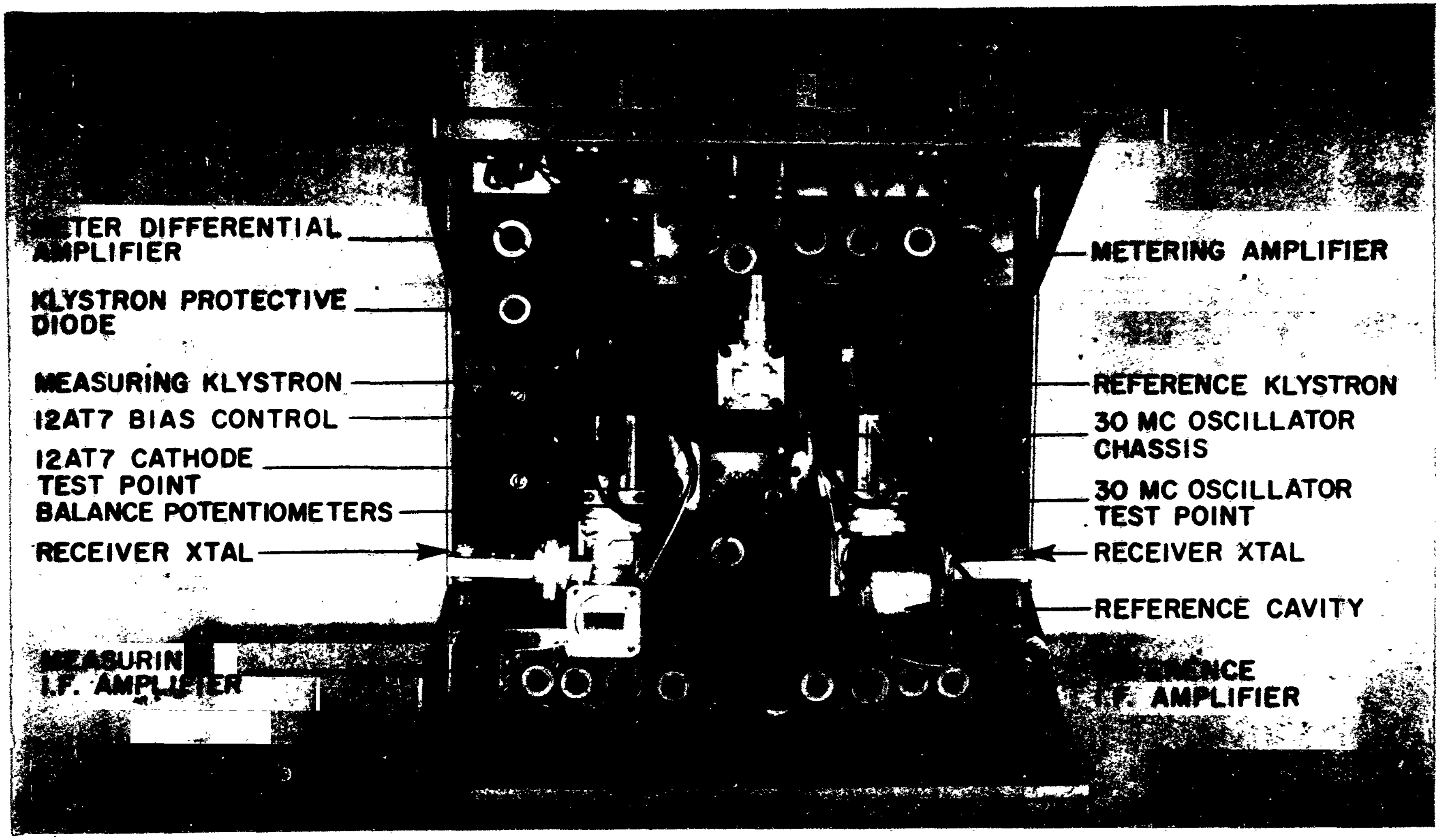
RECORDING MICROWAVE REFRACTOMETER

FIG. 1



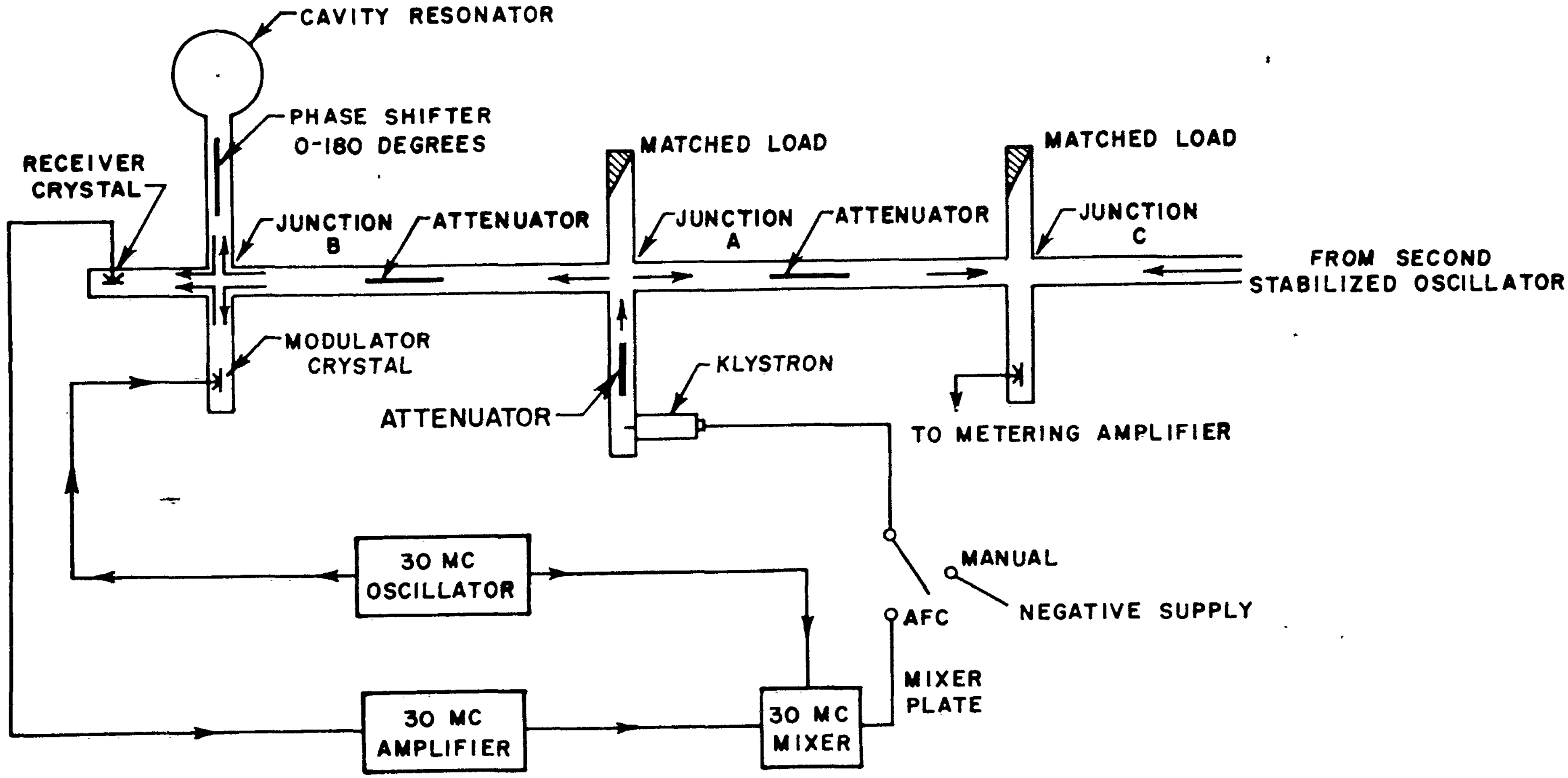

BLOCK DIAGRAM OF REFRACTOMETER

FIG. 2



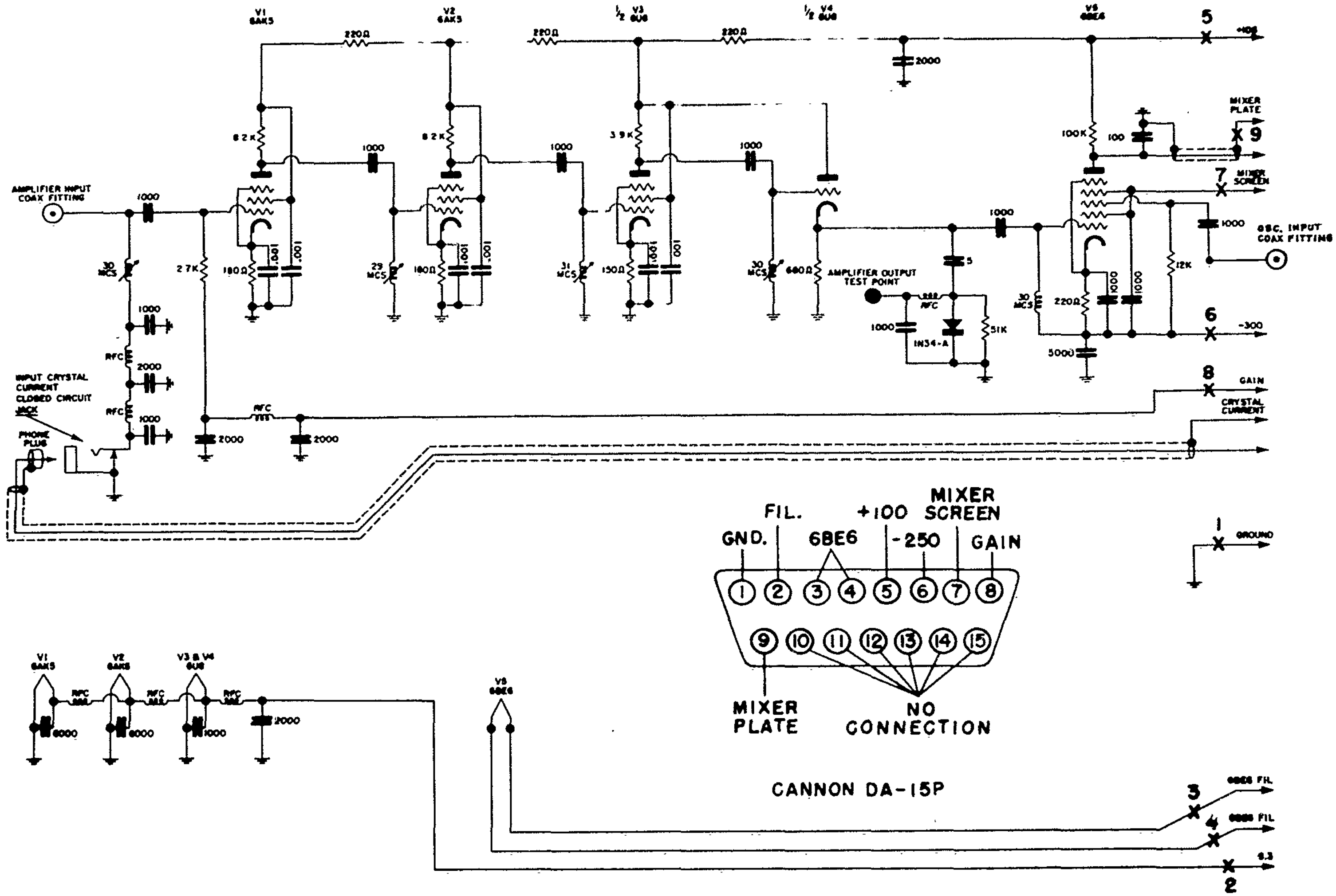

TOP VIEW OF REFRACTOMETER CHASSIS

FIG. 3



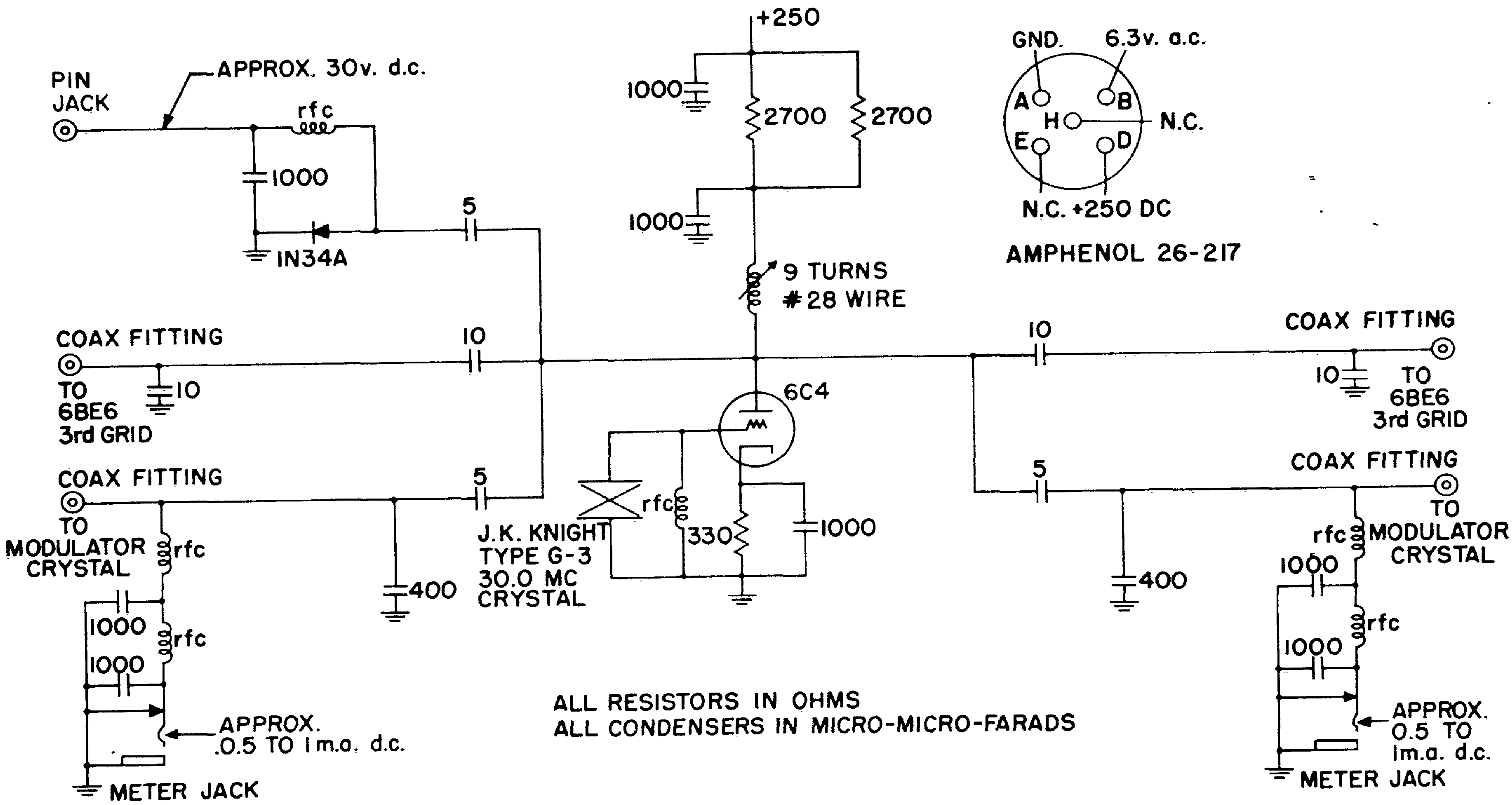

BLOCK DIAGRAM OF STABILIZED OSCILLATOR

FIG. 4



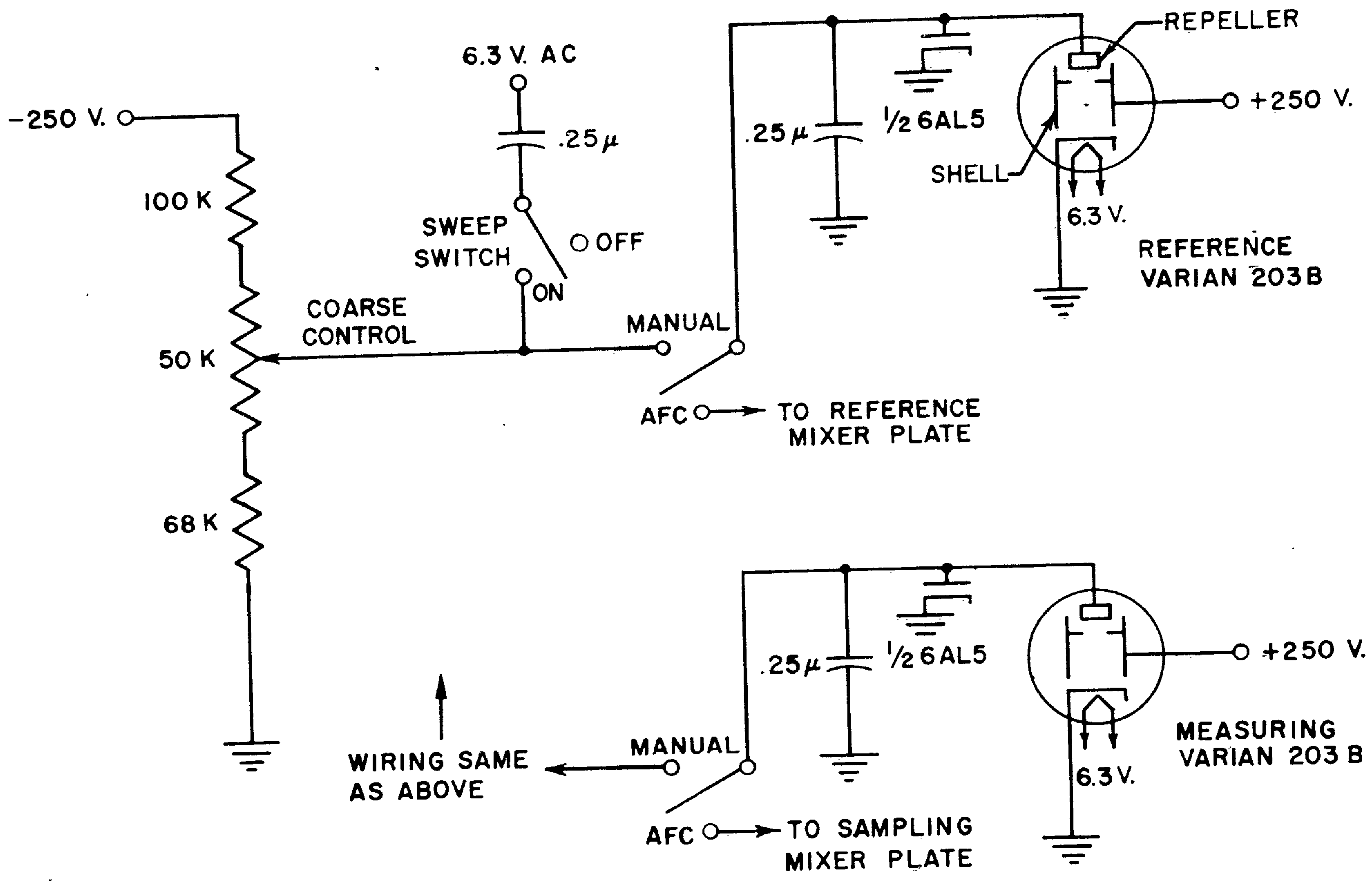

SCHEMATIC DIAGRAM OF 30 MSC AMPLIFIER AND MIXER

FIG. 5



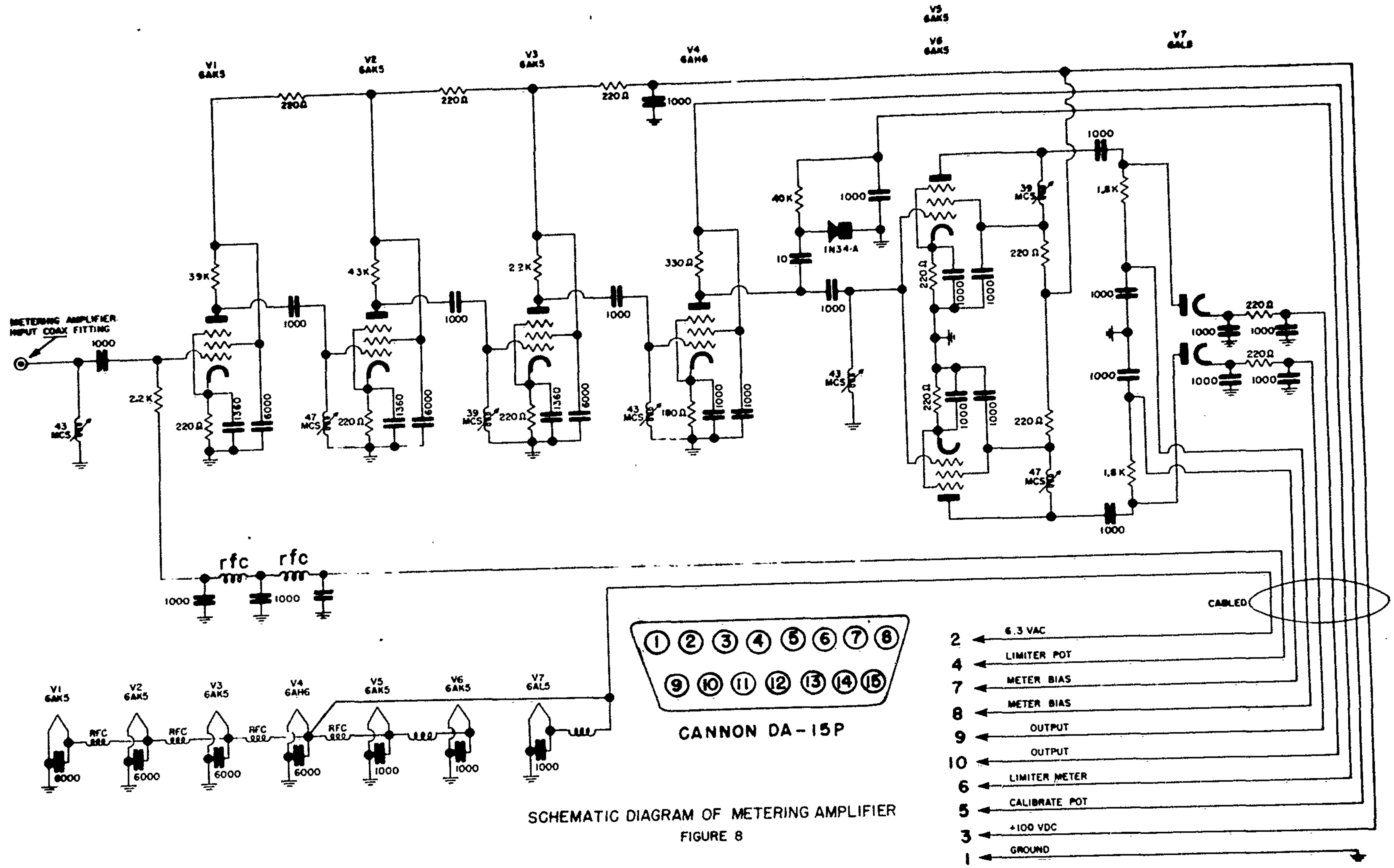

SCHEMATIC DIAGRAM OF 30.0 MC OSCILLATOR CHASSIS

FIG. 6



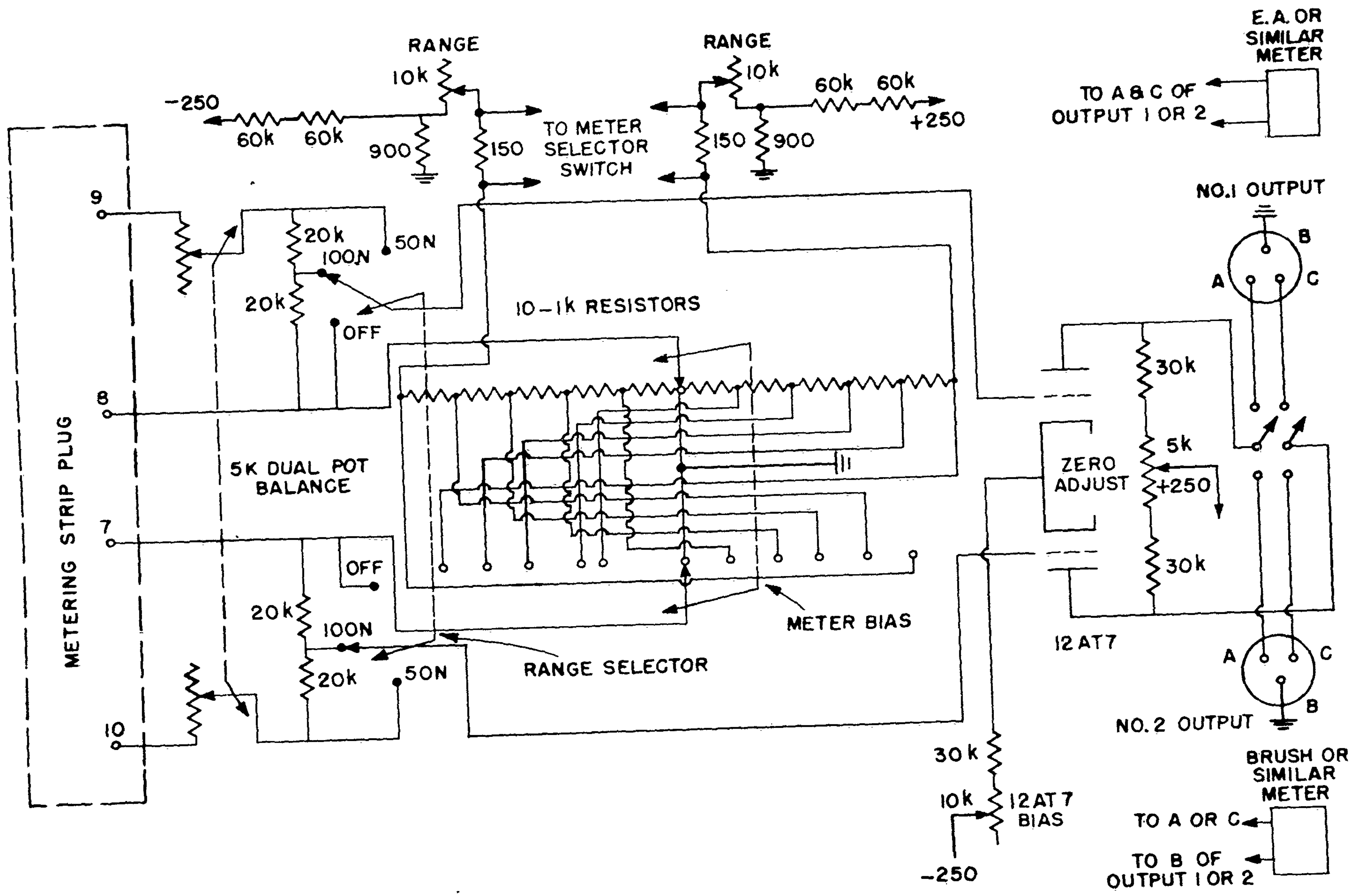

SCHEMATIC DIAGRAM OF KLYSTRON CIRCUITS

FIG. 7



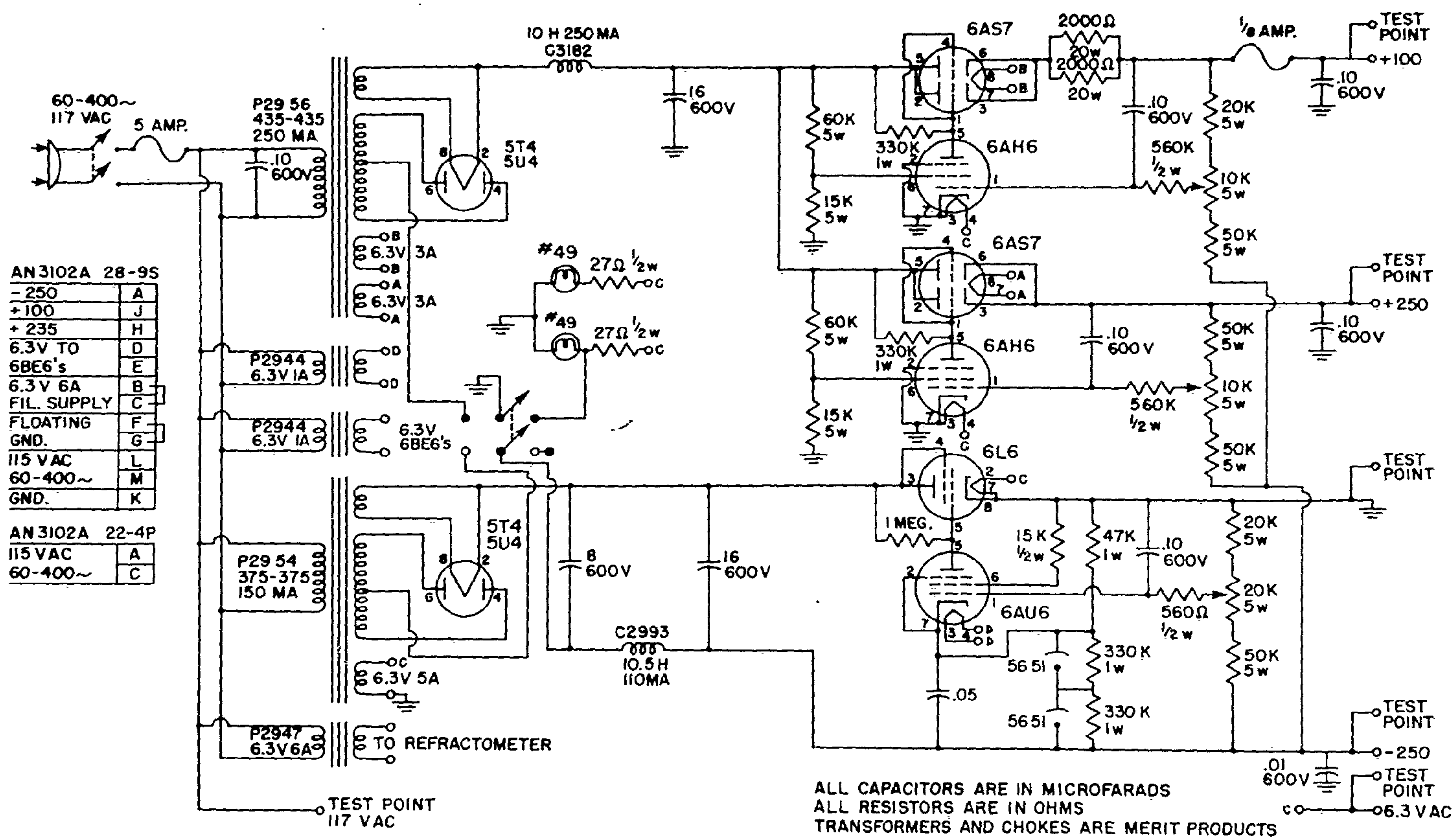

SCHEMATIC DIAGRAM OF METERING AMPLIFIER

FIGURE 8




RECORDING METER AMPLIFIER, SCALE SELECTOR AND PANEL ADJUSTMENT CIRCUITS

FIG. 9




POWER SUPPLY FOR RECORDING REFRACTOMETER

FIG. 10

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